Laboratory
2

Static Lateral-Directional Stability

The dSpace Flight Simulator Is Used to Asses Elements of Static Lateral-Directional Stability Using a Steady Heading Sideslip

Introduction

The purpose of this experiment is to assess the static lateral-directional stability of an aircraft. A steady heading sideslip is introduced as a flight test technique to measure the balance of forces and moments on an aircraft generated during a steady heading sideslip.

A. Quick Start Procedures for the dSpace Simulator. The student will execute the proper procedures for turning on the equipment and loading the aircraft simulation required of this lab.

B. Lateral-Directional Theory. A brief, selected review of the governing equations involving lateral-directional statics is presented. The focus is on those principles required to analyze the steady heading sideslip maneuver.

C. Flight Test: Steady Heading Sideslip. The student will learn to hold the aircraft simulation in a steady heading sideslip. Control Desk will be used to monitor and record control surface position, and lateral-directional displacement. The student will learn how to disable selected longitudinal dynamics if required to adequately control the simulation.

D. Data Reduction. The student will learn how to reduce data from a flight test in order to estimate key lateral-directional stability derivatives.

Part A. Quick Start Procedures for the dSpace Simulator

A detailed description of the dSpace flight simulator can be found in Lab 1, parts A through E. This lab assumes a basic knowledge of the simulator and its operating procedures. The below steps are the major steps in booting the dSpace simulator.

- ❑ Turn the Dome and Dukane projectors on.
- ❑ Boot the four simulator PCs. Note: Sim PC password is “netman.”
- ❑ Establish the serial connections (Serial Link), and start AVDS (Simulation Init | Matlab_AC.ini) on the Dome and OVHD PCs.
- ❑ Start Control Desk on Sim PC; resize window.
- ❑ Open the BasicAircraft.cdx experiment in the C:\Experiments\BasicAircraft directory.
- ❑ Double click on the “aircraft_d.mdl” file in the Experiment file browser.

- Move to the Models directory in Matlab.

- Type "MasterPanel" at the command prompt. Choose "Select Aircraft" from the figure, and load the Navion aircraft data.

Part B. Lateral-Directional Theory

The lateral-directional stability and control of an aircraft is inherently more complex than is the longitudinal stability and control. This is primarily due to the coupling of the lateral and the directional modes. For instance, most aircraft can be banked using the rudder alone. This is due to the coupling between the directional mode (heading) and the lateral mode (roll). Furthermore, the lateral mode (roll) has no inherent static stability. Additionally, the control surfaces for each mode have cross coupling effects into the other mode. For instance, aileron deflection not only causes a rolling moment (desired), but also causes a yawing moment (typically not desired). Likewise, the rudder rolls the airplane as well as causing it to yaw. Finally, the aileron control surfaces are unique in that they are a rate, vice displacement control. A constant aileron deflection results in a constant roll rate (after a few seconds). For these reasons, it is impossible to effectively decouple the governing equations. The solution of the governing equations is, at best, the solution to a system of linear equations. The dynamic motion is particularly complex and interesting, and we will approach that in Lab 3. To begin to build our understanding of the lateral-directional modes, we will explore static, equilibrium conditions at non-zero sideslip angles.

There are three lateral-directional degrees of freedom. Each may be represented by an appropriate differential equation, one describing lateral motion, one rolling motion, and one yawing motion. If we define equilibrium flight to mean that the aircraft is neither rolling nor yawing, then both the rolling moment and yawing moment must be zero. Hence, we can write,

Yawing Moment $$C_{n_0} + C_{n_\beta}\beta + C_{n_{\delta r}}\delta r + C_{n_{\delta a}}\delta a = 0$$

Rolling Moment $$C_{l_0} + C_{l_\beta}\beta + C_{l_{\delta r}}\delta r + C_{l_{\delta a}}\delta a = 0$$

With an eye towards the steady heading sideslip maneuver, we can further restrict the aircraft to be holding a constant heading. This implies that any side force acting on the aircraft fuselage and vertical tail be balanced by an appropriate component of the lift vector acting through a suitable bank angle. Hence, we can write,

Side force $$C_{Y_0} + C_{Y_\beta}\beta + C_{Y_{\delta r}}\delta r + C_{Y_{\delta a}}\delta a + C_L\phi = 0$$

Notice that these represent three algebraic equations. For a fixed set of stability derivatives, the free variables are aileron and rudder deflection, bank angle, and sideslip angle. A solution to these equations would correspond to a static, equilibrium flight condition termed a steady heading sideslip.

Dihedral Effect & Weathercock Stability

The dominant aerodynamic derivatives in the above equations are C_{n_β} and C_{l_β}. The first derivative is termed the weathercock stability of the aircraft. A positive value indicates stable directional stability, i.e. positive sideslip (wind in the right ear) produces a positive (nose right) yawing moment. The destabilizing influence of the fuselage and nacelles are overcome by the effect of the vertical stabilizer. The second derivative is termed the dihedral effect. A negative value indicates stable lateral stability, i.e. a positive angle of bank generates a positive sideslip, which in turn, generates a negative rolling moment thus acting to level the wings.

Dihedral effect is the result of numerous factors in the design of the aircraft. Some, but not all, include wing geometric dihedral, aspect ratio, and wing placement in relation to the fuselage. As a result, the value of this derivative can be difficult to estimate analytically. One of the results of our flight test will be to determine its value. The weathercock stability derivative is somewhat easier to analytically estimate since it is primarily influenced by the vertical tail volume. However, since the governing equations are coupled, its value will also be solved for in our test flight.

By differentiating the above set of equations with respect to sideslip angle, the constant terms can be eliminated. Useful relationships for the variations of rudder position, aileron position, and bank angle with sideslip angle in steady heading flight can be developed. Differentiation yields:

Yawing Moment
$$C_{n_\beta} + C_{n_{\delta r}} \frac{\delta r}{\delta \beta} + C_{n_{\delta a}} \frac{\delta a}{\delta \beta} = 0$$

Rolling Moment
$$C_{l_\beta} + C_{l_{\delta r}} \frac{\delta r}{\delta \beta} + C_{l_{\delta a}} \frac{\delta a}{\delta \beta} = 0$$

Side force
$$C_{Y_\beta} + C_{Y_{\delta r}} \frac{\delta r}{\delta \beta} + C_{Y_{\delta a}} \frac{\delta a}{\delta \beta} + C_L \frac{\delta \phi}{\delta \beta} = 0$$

C. Flight Test: Steady Heading Sideslip

We are limiting our discussion in this lab to stick-fixed motion. In reversible flight control systems, such as is found in the Navion, there is a significant difference between the stick-fixed and stick-free behavior of the aircraft. Specifically with regard to the rudder, stick-free motion can result in a condition called rudder lock. Since the reversible nature of the Navion controls are not modeled in this simulation, the rudder lock condition will not apply.

We are going to assume that the aircraft control derivatives, C_{Y_δ}, C_{n_δ}, and C_{l_δ} have been suitably determined from wind tunnel tests or analytic methods. You are going to stabilize the aircraft at various sideslip angles in level flight while holding a constant heading. At each sideslip angle, you will record the aileron and rudder deflection, as well as the sideslip and bank angle. If done carefully and correctly, the result will be a linear relationship between aileron deflection, rudder deflection, and bank angle when graphed against sideslip angle. Suitably reduced, this flight test data in conjunction with the equilibrium equations will result in an estimate of the dihedral effect derivative as well as the weathercock stability derivative.

- Bring up the Simulink model, "aircraft_D.mdl". Under the "Simulation" menu, select "Simulation Parameters | Real-time Workshop | Build".
- Select "Start" in AVDS if you have not already done so in order to see the aircraft motion. Since we are interested only in lateral dynamics, we can restrict some longitudinal dynamics. Put the pilot view with HUD on the dome. You will need to fly from the dome as it is the only station with independent rudder and aileron controls.

- ❑ In Control Desk, Select Animation Mode for the layout pages, and bring forward the layout page labeled "Integrators."
- ❑ Disable the velocity integrator. Be sure that the aircraft is at the trimmed flight condition when the integrator is disabled. You should recognize this from the first lab as having the effect of disabling the long period dynamic response. This will aid you considerable in holding performing the steady heading sideslip.
  - o If you are having a lot of trouble controlling the aircraft simulation in a steady heading sideslip later in the lab, you can disable the remaining longitudinal dynamics. Only do this as a last resort as an important part of the lab is gaining an appreciation for the pilot workload of the flight test maneuver.
- ❑ Gently feed in a small amount of rudder (approximately 5 degrees) until the aircraft has stabilized in a sideslip. Note: you will have to simultaneously deflect the ailerons to counter the rolling moment generated by the sideslip angle.
- ❑ Check you heading and see if it is constant. If not, roll the aircraft into a slight angle of bank to counter the side force generated by the non-zero sideslip angle and stop the turn.
- ❑ When you have the heading constant, the sideslip angle constant, and the aileron deflection constant, record your control deflections and displacement angles (bank & sideslip).
- ❑ Repeat the procedure at different sideslip angles.
  - o Attempt to take data points all the way up to full rudder deflection. It is possible that you may run out of aileron control to counter the rolling moment before you run out of rudder throw. In that case, take data points up to the point where you can no longer counter the rolling moment with full aileron deflection.

Shutdown

You can shutdown each software application. When prompted by Control Desk or MATLAB, DO NOT SAVE ANY CHANGES. You a file manager to move your flight test data files to a floppy. The files are in the Experiment/BasicAircraft/CapturedData directory.

- ❑ Shutdown the computers, and turn of the Dome and Dukane projectors.

D. Data Reduction (Deliverables)

Prepare a "Results & Analysis" report that explains the results of your flight test. You will reduce you data in two steps. First, you will attempt to estimate the linear relationship between control deflections (both), bank angle, and sideslip angle. Second, you will use these graphical estimates of the derivatives, $\frac{\delta r}{\delta\beta}$, $\frac{\delta a}{\delta\beta}$, and $\frac{\delta\phi}{\delta\beta}$, along with the lateral-directional equilibrium equations to estimate the weathercock stability and dihedral effect derivatives.

- For the range of sideslip angles tested, plot rudder deflection versus sideslip angle, aileron deflection versus sideslip angle, and bank angle versus sideslip angle.

- Each relationship should be approximately linear. Use a least squares fit to estimate values for $\frac{\delta r}{\delta \beta}$, $\frac{\delta a}{\delta \beta}$, and $\frac{\delta \phi}{\delta \beta}$. Keep in mind that for our purposes, the relationships should pass through the origin and be symmetric with respect to sideslip angle since asymmetric configurations or power plant effects are not modeled.

- Use the appropriate aircraft and flight condition data to solve for your coefficient of lift during the flight test.

- Combine your estimates with the equilibrium equations and the given control derivatives to solve for the unknown stability derivatives.

$$C_{Y_{\delta r}} \frac{\delta r}{\delta \beta} + C_{Y_{\delta a}} \frac{\delta a}{\delta \beta} + C_L \frac{\delta \phi}{\delta \beta} = -C_{Y_\beta}$$
$$C_{l_{\delta r}} \frac{\delta r}{\delta \beta} + C_{l_{\delta a}} \frac{\delta a}{\delta \beta} = -C_{l_\beta}$$
$$C_{n_{\delta r}} \frac{\delta r}{\delta \beta} + C_{n_{\delta a}} \frac{\delta a}{\delta \beta} = -C_{n_\beta}$$

- Compare and contrast your flight test results with the values given in the Addendum.

Addendum

Navion Aircraft Data from Nelson, "Flight Stability and Automatic Control"

Aircaft Data: W = 2750lbs S = 184 sq ft c = 5.7 ft

Control Derivatives (Assume these have been obtained from wind tunnel tests)

$$C_{l_{\delta a}} = -0.134$$
$$C_{l_{\delta r}} = 0.0107$$
$$C_{Y_{\delta a}} = 0.0$$
$$C_{Y_{\delta r}} = 0.157$$
$$C_{n_{\delta a}} = -0.0035$$
$$C_{n_{\delta r}} = -0.072$$

Stability Derivatives (Use the steady heading sideslip to determine your own estimate for these)

$$C_{Y_\beta} = -0.564$$
$$C_{n_\beta} = 0.071$$
$$C_{l_\beta} = -0.074$$